

**This Page Is Inserted by IFW Operations
and is not a part of the Official Record**

BEST AVAILABLE IMAGES

**Defective images within this document are accurate representations of
the original documents submitted by the applicant.**

Defects in the images may include (but are not limited to):

- **BLACK BORDERS**
- **TEXT CUT OFF AT TOP, BOTTOM OR SIDES**
- **FADED TEXT**
- **ILLEGIBLE TEXT**
- **SKEWED/SLANTED IMAGES**
- **COLORED PHOTOS**
- **BLACK OR VERY BLACK AND WHITE DARK PHOTOS**
- **GRAY SCALE DOCUMENTS**

IMAGES ARE BEST AVAILABLE COPY.

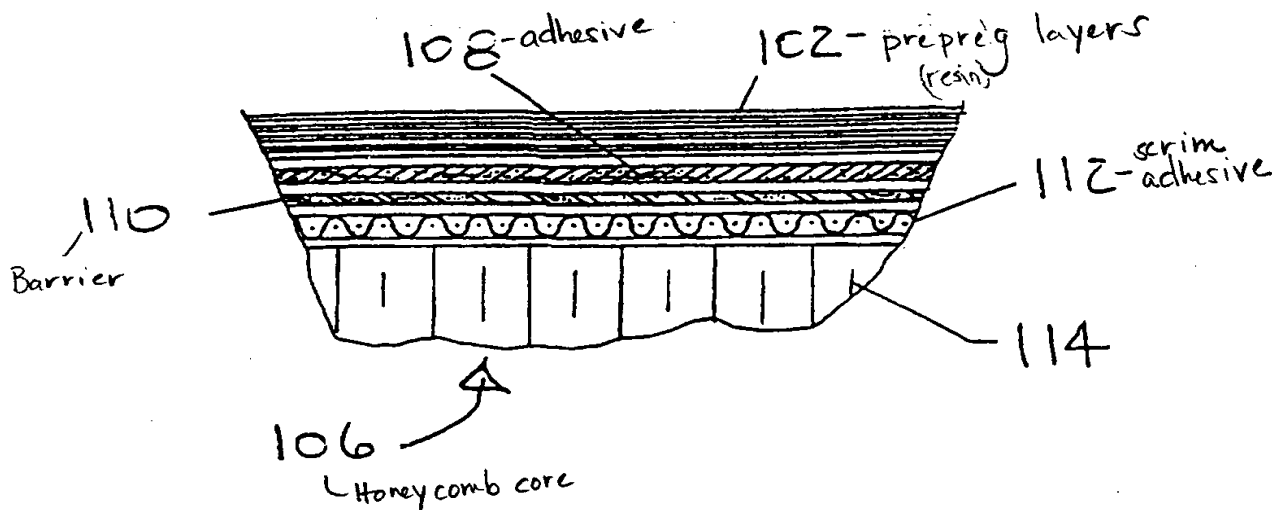
**As rescanning documents *will not* correct images,
please do not report the images to the
Image Problem Mailbox.**

THIS PAGE BLANK (USPTO)



(51) International Patent Classification ⁶ : B32B 3/12, 7/12		A1	(11) International Publication Number: WO 97/25198
			(43) International Publication Date: 17 July 1997 (17.07.97)
(21) International Application Number: PCT/US97/00075		(81) Designated States: AL, AM, AT, AU, AZ, BB, BG, BR, BY, CA, CH, CN, CZ, DE, DK, EE, ES, FI, GB, GE, HU, IL, IS, JP, KE, KG, KP, KR, KZ, LK, LR, LS, LT, LU, LV, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, TJ, TM, TR, TT, UA, UG, UZ, VN, ARIPO patent (KE, LS, MW, SD, SZ, UG), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, ML, MR, NE, SN, TD, TG).	
(22) International Filing Date: 6 January 1997 (06.01.97)			
(30) Priority Data: 5,604,010 <div style="display: flex; align-items: center;"> <div style="margin-right: 10px;"> <i>find</i> — [<div style="display: inline-block; vertical-align: middle; text-align: center;"> 08/587,160 08/616,903 08/620,829 </div> <div style="display: inline-block; vertical-align: middle; text-align: center;"> 11 January 1996 (11.01.96) 15 March 1996 (15.03.96) 20 March 1996 (20.03.96) </div> <div style="display: inline-block; vertical-align: middle; text-align: center;"> US US US </div> </div> </div>			
(71) Applicant: THE BOEING COMPANY [US/US]; P.O. Box 3707, M.S. 13-08, Seattle, WA 98124-2207 (US).		Published <i>With international search report. Before the expiration of the time limit for amending the claims and to be republished in the event of the receipt of amendments.</i>	
(72) Inventors: HARTZ, Dale, E.; 21316 - 188th Avenue S.E., Renton, WA 98058 (US). HOPKINS, William, B.; 2740 Mountlake Boulevard E., Seattle, WA 98112 (US). PEDERSON, Christopher, L.; 4749 - 37th Avenue S.W., Seattle, WA 98126 (US). ERICKSON, Dave, G.; Apartment #168, 15031 B. Military Road South, Seatac, WA 98108 (US). CORBETT, Darrell, H.; 26025 S.E. 192nd Street, Maple Valley, WA 98038 (US). SMITH, Stuart, A.; 10923 S.E. 220th Place, Kent, WA 98031 (US).			
(74) Agent: HAMMAR, John, C.; The Boeing Company, P.O. Box 3707, M.S. 13-08, Seattle, WA 98124-2207 (US).			

(54) Title: COMPOSITE HONEYCOMB SANDWICH STRUCTURE



(57) Abstract

We eliminate resin flow into the cells of honeycomb in sandwich structure by using an unsupported film adhesive (108), a barrier layer (110), and a scrim supported adhesive layer (112) between the composite laminate (102) and the core (106). We produce superior panels with lighter weights, improved mechanical properties, and more predictable structural performance by keeping resin in the laminate rather than losing it to the core cells. We reduce core crush and ply wrinkling in composite honeycomb sandwich structure by preventing slipping of tiedown plies relative to the mandrel and to one another during autoclave curing. We produce superior panels with lighter weights, improved mechanical properties, and more predictable structural performance. The method involves applying a film adhesive to the tiedown plies in the margin of the part outside the net trim line. During heating of the autoclave and prior to the application of high pressure to the composite structure, the film adhesive cures to form a strong bond between the plies and to the mandrel. When pressure is applied, the tiedown plies are locked together and to the mandrel to prevent slippage between any layers in the panel.

FOR THE PURPOSES OF INFORMATION ONLY

Codes used to identify States party to the PCT on the front pages of pamphlets publishing international applications under the PCT.

AM	Armenia	GB	United Kingdom	MW	Malawi
AT	Austria	GE	Georgia	MX	Mexico
AU	Australia	GN	Guinea	NE	Niger
BB	Barbados	GR	Greece	NL	Netherlands
BE	Belgium	HU	Hungary	NO	Norway
BF	Burkina Faso	IE	Ireland	NZ	New Zealand
BG	Bulgaria	IT	Italy	PL	Poland
BJ	Benin	JP	Japan	PT	Portugal
BR	Brazil	KE	Kenya	RO	Romania
BY	Belarus	KG	Kyrgyzstan	RU	Russian Federation
CA	Canada	KP	Democratic People's Republic of Korea	SD	Sudan
CF	Central African Republic	KR	Republic of Korea	SE	Sweden
CG	Congo	KZ	Kazakhstan	SG	Singapore
CH	Switzerland	LI	Liechtenstein	SI	Slovenia
CI	Côte d'Ivoire	LK	Sri Lanka	SK	Slovakia
CM	Cameroon	LR	Liberia	SN	Senegal
CN	China	LT	Lithuania	SZ	Swaziland
CS	Czechoslovakia	LU	Luxembourg	TD	Chad
CZ	Czech Republic	LV	Latvia	TG	Togo
DE	Germany	MC	Monaco	TJ	Tajikistan
DK	Denmark	MD	Republic of Moldova	TT	Trinidad and Tobago
EE	Estonia	MG	Madagascar	UA	Ukraine
ES	Spain	ML	Mali	UG	Uganda
FI	Finland	MN	Mongolia	US	United States of America
FR	France	MR	Mauritania	UZ	Uzbekistan
GA	Gabon			VN	Viet Nam

COMPOSITE HONEYCOMB SANDWICH STRUCTURE

Technical Field

The present invention relates to composite honeycomb sandwich structure, and particularly to resin impregnated fabric sheets forming outer skins adhered on opposed surfaces of a honeycomb core with an intermediate barrier to eliminate resin flow from the skins to the core.

Background Art

Aerospace honeycomb core sandwich panels (having composite laminate skins cocured with adhesives to the core through autoclave processing) find widespread use today because of the high stiffness-to-weight (*i.e.*, "specific stiffness") and strength-to-weight (*i.e.*, specific strength) ratios the panels afford. Typical honeycomb core sandwich panels are described in U.S. Patents 5,284,702; 4,622,091; and 4,353,947. *Alteneder et al.*, *Processing and Characterization Studies of Honeycomb Composite Structures*, 38th Int'l SAMPE Symposium, May 10-13, 1993 (PCL Internal No. 200-01/93-AWA) discusses common problems with these panels, including core collapse (*i.e.*, core crush), skin laminate porosity, and poor tool surface finish.

U.S. Patent 5,445,861 describes composite sandwich structure for sound absorption (acoustic insulation) and other applications. The sandwich structures have seven layers as follows:

- (1) an outer skin;
- (2) a small celled honeycomb or foam core;
- (3) a frontside inner septum;
- (4) a large celled middle honeycomb core;
- (5) a backside, inner septum;
- (6) a backside, small celled honeycomb or foam core; and

(7) an inner skin.

Tuned cavity absorbers in the middle honeycomb core absorb sound. Performance of this structure suffers from resin flow to the cells of the honeycomb cores during fabrication for the reasons already discussed and because such flow alters the resonance of the structure.

Summary of the Invention

With a high flow resin system, large amounts of resin can flow into the core during the autoclave processing cycle. Such flow robs resin from the laminate, introduces a weight penalty in the panel to achieve the desired performance, and forces over design of the laminate plies to account for the flow losses. The resin loss from the laminate plies also reduces the thickness of the cured plies which compromises the mechanical performance. To achieve the desired performance and the corresponding laminate thickness, additional plies are necessary with resulting cost and weight penalties. Because the weight penalty is severe in terms of the impact on vehicle performance and cost in modern aircraft and because the flow is a relatively unpredictable and uncontrolled process, aerospace design and manufacture dictates that flow into the core be eliminated or significantly reduced. In addition to the weight penalty from resin flow to the core, we discovered that microcracking that originated in the migrated resin could propagate to the bond line and degrade mechanical performance. Such microcracking potential poses a catastrophic threat to the integrity of the panel and dictates that flow be eliminated or, at least, controlled.

Flow from the laminates to the core occurs because of viscosity reduction of the resin (*i.e.*, thinning) at the elevated processing temperatures. Therefore, prior art attempts to solve the flow problem have generally focused on retaining the ambient temperature viscosity of the resin at the curing temperatures. For example, one might alter the processing cycle to initiate

curing of the resin during a slow heat-up, low pressure step to induce resin chain growth before high temperature, high pressure completion. In this staged cure cycle, one would try to retain the resin's viscosity by building molecular weight at low temperatures. Higher molecular weight resins have inherently higher viscosity so they remain thicker and are resistant to damaging flow to the core. Unfortunately, with a staged cure cycle, too much flow still occurs, and the potential problems of microcracking still abound. Also, facesheet porosity might increase beyond acceptable limits. Furthermore, a modified cure cycle increases autoclave processing time. Increased processing time translates to a significant fabrication cost increase with risk of rejection of high value parts at the mercy of uncontrolled and inadequately understood factors.

We eliminate resin (matrix) flow into the honeycomb core for sandwich structure using high flow resin systems and results in reproducibility and predictability in sandwich panel fabrication and confidence in the structural performance of the resulting panel. We use a scrim-supported barrier film between the fiber-reinforced resin composite laminates and the honeycomb core. This sandwich structure is lighter for the same performance characteristics than prior art panels because the resin remains in the laminate (skin) where it provides structural strength rather than flowing to the core where it is worthless, introducing excess weight and potential panel failure. We also generally use an unsupported film adhesive between the barrier film and the laminates to bond the laminates to the barrier film. With these layers (which might be combined into one product), they achieved improved performance, retained the resin in the laminates and thereby reduced excess resin that designers otherwise needed to design into the panels to account for resin flow into the core, and reliably fabricated panels in which they had structural confidence.

Core crush frequently occurred in the chamfer region of honeycomb core when we cured a panel having a scrim-supported barrier film, particularly

when they tried to use lighter weight core materials. We can reduce core crush in these panels by including a tiedown ply in contact with the core beneath the barrier film (and adhesive) because the tiedown ply reduced slippage of the barrier film relative to the core during curing.

Controlling core slippage in the present invention allows us to use lighter density honeycomb core to produce structures without costly scrap due to core crush. We reduce manufacturing costs both by saving time, materials, and rework/scrap and by improving the reliability of the manufacturing process to produce aerospace-quality panels having the highest specific strength and specific stiffness.

The added tiedown ply means that three or more tiedown plies will be included in the final preform of the panel. In conventional practice, there will also be tiedown plies on the outer surfaces of the panel and possibly between the laminate and the adhesive barrier film. Each tiedown ply extends outwardly from the part beyond the net trim line of the finished product. Conventionally, the tiedown plies are secured individually and sequentially to the layup mandrel with tape. Especially when using low density core it is important to fix the relation of the plies to one another and to the mandrel. Failure of the tape results in facesheet ply wrinkles or core crush. Core crush could still occasionally occur when the tiedown ply in contact with the core pulled away from the tape securing it to the mandrel, slipping relative to the other tiedown plies. The adhering strength of the tape alone was insufficient to overcome the forces acting on the core in a panel when we applied autoclave pressure. We discovered how to adhere the tiedown plies to each other reliably, easily, and inexpensively. Adhering the plies to each other distributes the forces acting on any individual ply among all the tiedown plies, reducing the maximum force seen by the tape adhering the tiedown plies to the mandrel. While described with respect to a composite honeycomb sandwich structure,

the adhering method is generally applicable to all applications involving tiedown plies in composite construction.

Thus, in one aspect, the present invention relates to an improvement in the manufacture of composite structure, especially composite honeycomb sandwich structure, where tiedown plies are used to secure the part during autoclave curing at elevated temperature and pressure. To lock the tiedown plies together so that there is no movement of one ply relative to another, we use a lower temperature curing adhesive to cure and to connect the several plies together during the early stages of autoclave curing prior to applying pressure. We apply the adhesive outside the net trim line for the part, so that it is removed during finishing of the part.

In another aspect, the present invention relates to adhering tiedown plies to one another during the construction of composite structure, especially during the autoclave processing at elevated temperature and pressure of composite honeycomb sandwich structure. The conventional practice of taping the tiedown plies to the mandrel alone is unsatisfactory, because the taping must be sufficient to prevent slippage of any ply or of one ply relative to another. We discovered that we could adhere the plies effectively to one another to reduce maximum forces on the tape by applying a low temperature curing film adhesive between the tiedown plies just outside the net trim line for the part. In the autoclave, this film adhesive melts and cures at a lower temperature than the resin in the laminates so that it bonds the tiedown plies together prior to increasing the autoclave pressure at the higher temperature where the laminate resin flows and cures. The film adhesive eliminates movement of the tiedown plies relative to one another. In our preferred embodiment for a bismaleimide (BMI) sandwich panel, we prefer to use an adhesive that cures at about 250°F (121°C) for a BMI that cures around 375°F (191°C), and post-cures around 440 °F.

Brief Description of the Drawings.

Fig. 1 illustrates a typical composite honeycomb sandwich structure.

Fig. 2 is a schematic, partial sectional view of the skin-core interface in sandwich structure having a scrim-supported barrier film to prevent resin flow from the skin to the core.

Fig. 3 is a schematic, partial sectional view of prior art honeycomb sandwich structure, suffering resin flow to the core, using a supported film adhesive without a barrier film.

Fig. 4 is another schematic, partial sectional view showing sandwich structure with resin depletion in the skin, but where the resin is prevented from reaching the core with a bulging, unsupported barrier film.

Fig. 5 is a schematic, sectional elevation showing core crush of a honeycomb sandwich panel caused by core and barrier film slippage.

Fig. 6 is another schematic, sectional elevation showing the use of a tiedown ply to reduce core crush.

Fig. 7 is a graph of a typical autoclave curing cycle for making composite honeycomb sandwich panels, showing that our tiedown adhesive cures prior to the application of high pressure in the cycle.

Detailed Description of a Preferred Embodiment

As a frame of reference for this description, we will initially describe typical composite honeycomb sandwich structure. Then, we will turn to our invention of a method of reliably adhering the tiedown plies together.

A composite honeycomb sandwich panel minimizes, eliminates, or significantly reduces resin flow from the laminates to the core, thereby permitting a simpler processing cycle that is more robust for the manufacture of aerospace structure. Such a sandwich panel 100 (Fig. 1) generally has outer facesheets or skins 102 adhered to a central honeycomb core 106. The finished skins 102 comprise laminates of layers of fiber-reinforced organic matrix resin

in a cured and consolidated composite form. The core 106 can be paper, synthetic paper, metal, composite, or the like, as appropriate for the application. In panels of the present invention, we obtain higher specific strengths and higher specific stiffnesses because we reduce core crush during autoclave curing by incorporating at least one tiedown ply between the core 106 and skin 102 to reduce damaging slippage between the core and skin that otherwise often occurs.

To prevent flow of resin from the composite laminate skin to the core, we use an unsupported film adhesive 108 (Fig. 2), a barrier film 110, and a scrim-supported film adhesive 112 between the skin 102 and the core 106 to keep resin out of the cells 114 of the core 106.

Fig. 3 illustrates the core-filling problems that can result when a film adhesive 112 is used alone without the barrier film 110 and film adhesive 108. Cells 114 of the honeycomb fill with resin 118 which migrates from the laminates and which thereby depletes the resin in the skin 102. Resin depletion impacts structural performance because it reduces ply thickness. Resin depletion increases total weight since the cell resin 118 is simply waste. In all cases, uncontrolled resin flow and depletion makes the panel suspect, especially to microcracking that can begin in the cell resin 118 during thermal cycling and migrate to the fiber-reinforced skin 102, especially at the bond line between the skin 102 and core 106.

Fig. 4 illustrates undesirable bulging that can occur if a barrier film 110 is used without a scrim-supported film adhesive 112 to try to eliminate cell resin 118. Here, a waste resin bulge 120 protrudes downwardly into the cells 114 of the honeycomb core 106. While the resin is contained in the bulge 120, the skin 102 is still depleted in resin. The flow of resin to bulge 120 imposes structural performance and weight penalties comparable to the uncontrolled condition illustrated in Fig. 3.

As shown in Fig. 2 with the film adhesive 108, barrier film 110, and scrim-supported film adhesive 12, resin flow is checked without cell resin 118 or resin bulges 120. We discovered, however, that the barrier film produced a slip plane between the laminate skins and the core which often resulted in core crush during the autoclave processing cycle. In 22 of 31 test panels, in fact, we experienced core crush in our initial trials. This rate of failure was unacceptable from a cost and schedule perspective. Our tiedown plys in the chamfer region reduce the frequency of or eliminate damaging core slippage and the core crush attributable to such slippage.

For bismaleimide laminated skins made with RIGIDITE® 5250-4-W-IM7-GP-CSW, RIGIDITE® 5250-4-W-IM7-GP-CSX, and RIGIDITE® 5250-4-W-IM7-GP-PW prepreg from Cytec Engineered Materials, Inc. (Cytec), the film adhesive 108 preferably is 0.015 psf METLBOND® 2550U adhesive, also available from Cytec. The film adhesive provides additional resin to promote a quality bond between the laminate and barrier film 110. The barrier film 110 preferably is a 0.001 inch thick, bondable grade, surface treated KAPTON® polyimide barrier film capable of withstanding the cure cycle to provide a resin impermeable membrane between the skin 102 and core 106. The scrim preferably is fiberglass, "Style 104" fiber cloth and the film adhesive 112 is 0.06 psf METLBOND® 2550G adhesive, available from Cytec. The scrim-supported film adhesive prevents the barrier film from bulging into the core cells, thereby retaining the resin in the laminate (i.e., skin layers) so that the cured ply thickness is maximized and thereby, we achieve maximum performance at minimum weight for the panels.

The film adhesive 108, barrier film 110, and film adhesive 112 can be purchased as a single item from Cytec as METLBOND® 2550B-.082 36".

The plys of the skin 102 typically are prepregs of carbon fiber impregnated with bismaleimide thermoset resin, although the present invention applies to other resin systems. Tows might be used in place of the prepreg.

The film adhesive 108 should be tailored to achieve an adequate bond between the skin 102 and barrier film 110. The honeycomb core generally is HRP Fiberglass Reinforced Phenolic honeycomb available from Hexcel.

The supported film adhesive and barrier film layers in the sandwich structure also function as corrosion barriers between the skin 102 and core 106 in the case where the core is metal, such as aluminum, and the skin includes a galvanically dissimilar material, such as carbon fiber.

Additional information concerning preferred panels is presented in the technical paper: *Hartz et al.*, "Development of a Bismaleimide/Carbon Honeycomb Sandwich Structure," SAMPE, March, 1996, which we incorporate by reference. This paper describes both the *Hartz et al.* barrier film improvement, the tiedown ply method, and the adhering method of the present invention.

The *Hartz*-type panels provide mechanical and physical edgeband properties equivalent to solid BMI/carbon laminate (cured at 0.59 MPa (85 psig)). Our tests confirm that in our panels the edgeband cured-ply-thickness is equivalent to a solid laminate and that the edgeband 160 (Figs. 5 & 6) met the requirements of the solid laminate nondestructive inspection specification. The edgeband and facesheet mechanical performance improved over results we achieved with sandwich structure lacking the scrim-supported adhesive, barrier film, adhesive combination. The flatwise tensile mechanical performance also met design requirements.

Preconditioning the core to eliminate volatile evolution during curing by heating the core to about 235° C (455° F), prior to laying up the sandwich panel, especially for phenolic core, eliminates core-laminate disbonding otherwise caused by outgassing from the core.

Core crush 200 (Fig. 5) occurs in the chamfer region 155 when the barrier film 110 and core 106 slip relative to the facesheets 102 when autoclave pressure is applied and when the resin is melted. As shown in Fig. 5, the

barrier films 100 and core 106 have moved toward the right to compress the core in the chamfer region 155 to produce the core crush 200. The skin 102 has sagged in the edgeband region 160 where the core moved away.

Referring now to Fig. 6, the improved honeycomb sandwich panel includes at least one tiedown ply 150 in contact with the core 106 along a chamfer 155. Such a chamfer (*i.e.* an angled transition in the core, often at the edgeband 160) typically occurs around the periphery of the panel, but it might also occur intermediate of the panel at join lines or hard points where fasteners or pass-throughs might be necessary in the assembled structure.

Typically we use a single ply 150 of carbon fiber or fiberglass fabric with a conventional 0/90 fiber orientation in the fabrication of bismaleimide panels having 5 or 8 lb/ft³ HRP core, like *Hartz et al.* describe. The tiedown ply 150 functions to prohibit or to limit slippage of the skin relative to the core so as to reduce core crush otherwise attributable to the slippage. The tiedown ply 150 anchors the core with the inherent roughness of the fabric when the preform is heated during the autoclave processing cycle and the matrix resin softens, melts, and, for high flow resins, essentially liquefies. With these panels, we can save between 2.5-4 lb/ft³ of core because we can use lighter density honeycomb core without suffering core crush. For a fighter, this change can save as much as 25 lbs per vehicle.

As shown in Fig. 6, the tiedown ply 150 is a narrow, peripheral strip that contacts the core 106 along at least a portion of the chamfer 155 for about 1 inch overlap with the core 106 and extends outward into the edgeband 160 beyond the trimline 165 of the part. The tiedown ply 150 might be on either the flat side of the chamfer or the angled surface (which is how we show it in Fig. 6). The key factor is that the tiedown ply 150 contact the core beneath the adhesive and barrier film 110 which is used to bond the laminate skin to the core. The tiedown ply 150 is cutaway everywhere in the body of the part other than a narrow peripheral area in the chamfer region, and forms a peripheral

frame around the edge of the panel. In this way, the tiedown ply 150 allows an adhesive interface between the core 106 and the skins 102 in the panel region.

Traditionally, in making a *Hartz*-type panel, we use four complete cover sheet tiedown plies 175 in an effort to anchor the layers and the core, and we show all these plies in Fig. 6. These traditional plies 175 were commonly used in sandwich panel fabrication prior to introducing the *Hartz*-type barrier film, and we commonly use them all, although we believe we can now eliminate all but the outer plies and the peripheral, core contacting tiedown ply 150. That is, we would use three total plies rather than five, as Fig. 6 shows.

The tiedown plies 150 and 175 extend through the edgeband 160 beyond the net trim line 165 to anchoring points that we tape to the layup mandrel. To further prevent slippage of the tiedown plies, we have incorporated a low curing (*i.e.* 121°C for BMI panels) film adhesive 180 between the tiedown plies just outside the net trim line of the part. The film adhesive 180 eliminates movement of one ply relative to the others when we apply pressure during the autoclave curing cycle. Curing at a temperature of about 100 - 150°F below the curing temperature of the laminate resin, the tiedown adhesive cures before we need to increase the autoclave pressure and the cured adhesive bonds the tiedown plies to one another. Using the adhering method eliminates relative movement of the plies and eliminates facesheet wrinkles and core crush that otherwise can occur.

The tiedown method saves material, reduces cost, and saves weight, because it uses the "picture frame" peripheral tiedown ply 150 (with the traditional, internal sheets omitted). The normal tiedown procedure entails plies on the outer surfaces of the skins and internally between the skin and underlying adhesive (Fig. 5). A traditional tiedown system will fail without the "picture frame" ply because the barrier film 110 permits the core to slip. The Corbett and Smith method will fail occasionally without the adhering method of the present invention.

For lightweight core (*i.e.* 5-8 lb/ft³) with the bismaleimide prepreg and adhesive system previously described, we hold the chamfer angle to $20^{\circ} \pm 2^{\circ}$.

By "chamfer" we mean an angled, cut region (a ramp) of the honeycomb core tapering from full thickness to no thickness with a steady slope. A chamfer is used at the edge band of a composite honeycomb sandwich panel to provide a smooth transition between the structural body of the panel that has the embedded honeycomb and a connecting edge band lacking any honeycomb core. The method of the present invention allows us to use much steeper chamfer angles than traditional practices often require if one is to avoid core crush without one tiedown ply. While we prefer a 20° chamfer, we believe that we could increase the angle to whatever angle suited the panel design requirements.

By "autoclave processing" we mean the cycle of elevated temperature and pressure applied to the panel to consolidate and cure resin in the laminate while bonding or otherwise adhering the cured laminate to the honeycomb core. Our preferred cycle is illustrated in Fig. 7. Our adhesive for the tiedown plies cures at about 250°F (121°C) so it cures prior to the increase in autoclave pressure that can introduce relative motion between layers in the panel.

If core crush occurs, the damage to the panel is generally so extensive that repair is impossible so the part is scrapped. The cost of today's advanced composite resins and reinforcing fibers requires a process that virtually eliminates core crush. Otherwise, the processing costs are prohibitive. With panels being designed as close to the design edge as possible, core crush is a significant issue. The method of the present invention reduces cores crush and ply movement or wrinkling.

While we have described preferred embodiments, those skilled in the art will readily recognize alterations, variations, and modifications, which might be made without departing from the inventive concept. Therefore, interpret the claims liberally with the support of the full range of equivalents known to those

of ordinary skill based upon this description. The examples are given to illustrate the invention and are not intended to limit it. Accordingly, define the invention by the claims and limit the claims only as necessary in view of the pertinent prior art.

We claim:

1. Composite honeycomb sandwich structure, comprising:
 - (a) a honeycomb core, having core cells;
 - (b) at least one composite laminate having plies of fiber-reinforced matrix resin adhered to the core;
 - (c) a film barrier layer between the laminate and the core to bond the laminate and core and to eliminate resin flow from the laminate into the core cell; and
 - (d) a film adhesive with supporting scrim between the barrier layer and the core to eliminate resin flow to or sagging of the barrier film into the core cells.
2. The structure of claim 1 wherein the laminate includes bismaleimide matrix resin.
3. The structure of claim 1 wherein the barrier layer is a bondable grade, polyimide.
4. The structure of claim 2 wherein the film adhesive includes bismaleimide.
5. The structure of claim 4 further comprising an unsupported film adhesive layer between the barrier layer and the laminate.
6. A method for eliminating the flow of resin from laminate skins of a composite honeycomb sandwich panel to cells of the honeycomb comprising the step of:

containing the resin in the skin with a scrim supported barrier film that is impermeable to the resin and that is adhered between the skin and honeycomb.

7. A method for adhering tiedown plies together in the manufacture of composite structure, comprising the steps of:

- (a) assembling on the layup mandrel a composite preform in the shape of the composite structure, the preform having at least one resin-impregnated laminate and at least two tiedown plies; and
- (b) adhering the tiedown plies to one another with a film adhesive applied to the plies outside a net trim line of the composite structure.

wherein the film adhesive cures at a temperature lower than the resin in the laminate.

8. The method of claim 7 wherein the laminate includes bismaleimide matrix resin.

9. The method of claim 7 wherein the preform includes a barrier film made from a bondable grade, polyimide adjacent the laminate.

10. The method of claim 8 wherein the preform includes a honeycomb core and an adhesive between the barrier film and core.

11. The method of claim 10 wherein the preform includes a film adhesive layer between the barrier film and the laminate.

12. The method of claim 10 wherein the preform includes a supporting scrim between the barrier film adhesive and the core to prevent sagging of the barrier film into the core cells.

13. The method of claim 12 wherein the preform includes a tiedown ply in contact with the core between the adhesive and core.

14. A method for reducing core crush in a chamfered composite honeycomb sandwich panel having a resin-impregnated laminate adhered to a honeycomb core, the core having a chamfer, comprising the steps of:

- (a) contacting a tiedown ply with the honeycomb core of the panel in the region of the chamfer to prevent slippage between the core and the laminate; and
- (b) assembling tiedown plies over outer surfaces of the laminate;
- (c) adhering the tiedown plies together and to the layup mandrel with a lower temperature curing adhesive applied to the tiedown plies outside a net trim line of the panel,

wherein the adhesive melts and cures prior to the application of autoclave pressure and prior to the melt and flow of the resin in the laminate.

15. The method of claim 14 wherein the laminate includes a barrier film to prevent resin flow from facesheets of the laminate to the core cells, and wherein one tiedown ply is between the barrier film and core.

16. Composite honeycomb sandwich structure having improved resistance to core crush, comprising:
- (a) a honeycomb core, having core cells and a peripheral chamfer;
 - (b) at least one composite laminate having plies of fiber-reinforced matrix resin adhered to the core;
 - (c) a barrier film adhesive between the laminate and the core to bond the laminate and core and to eliminate resin flow from the laminate into the core cells; and
 - (d) a peripheral tiedown ply in contact with the chamfer of the core beneath the adhesive to eliminate slippage of the barrier film relative to the core and, in so doing, to reduce core crush.
17. The structure of claim 16 wherein the laminate includes bismaleimide matrix resin.
18. The structure of claim 16 wherein the barrier film is a bondable grade, polyimide.
19. The structure of claim 17 wherein the adhesive includes bismaleimide.
20. The structure of claim 19 further comprising a film adhesive layer between the barrier film and the laminate.
21. The structure of claim 16 further comprising a supporting scrim between the barrier film adhesive and the core to prevent sagging of the barrier film into the core cells.

22. Composite honeycomb sandwich structure resistant to core crush caused by slippage of a composite laminate along a chamfer of a honeycomb core, comprising:

- (a) a honeycomb core having a chamfer;
- (b) a tiedown ply contacting the chamfer; and
- (c) at least one laminate adhered to the core through the tiedown ply at the chamfer

wherein the tiedown ply prevents damaging slippage of the laminate relative to the core that would produce core crush during autoclave curing of the structure to adhere the core to the laminate.

23. A method for reducing core crush in a chamfered composite honeycomb sandwich panel having a laminate adhered to a honeycomb core, the core having a chamfer, comprising the step of:

contacting a tiedown ply with the honeycomb core of the panel in the region of the chamfer to prevent slippage between the core and the laminate.

24. The method of claim 23 wherein the laminate includes a barrier film to prevent resin flow from the laminate to the core cells.

Fig. 1

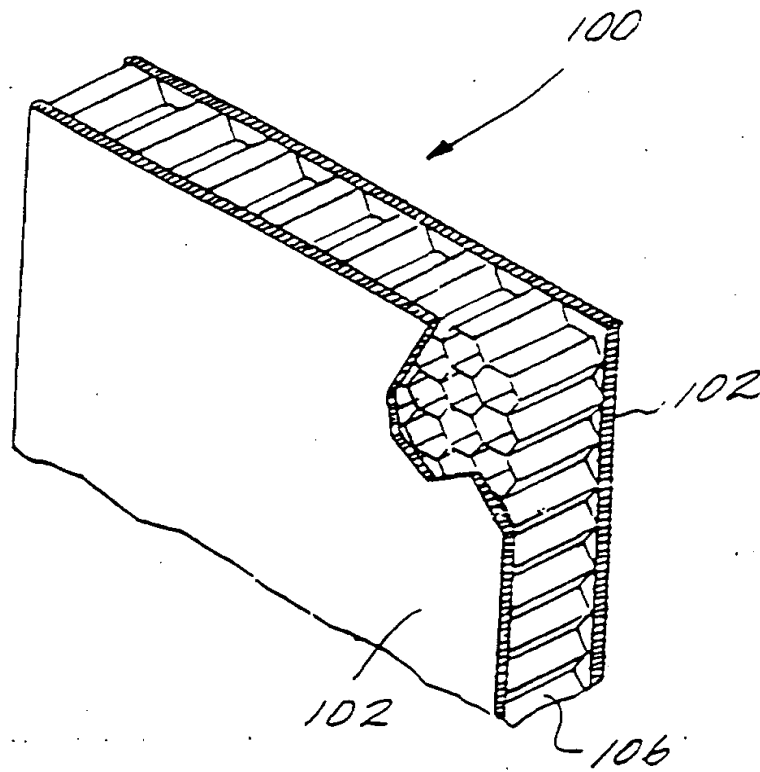


Fig. 2

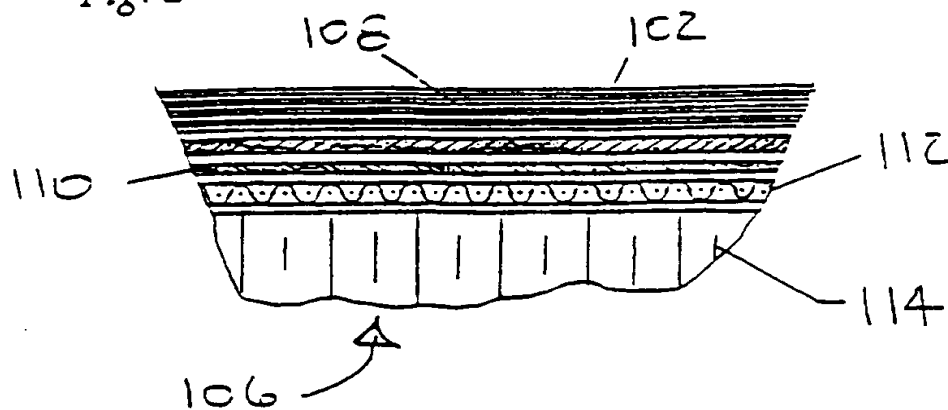
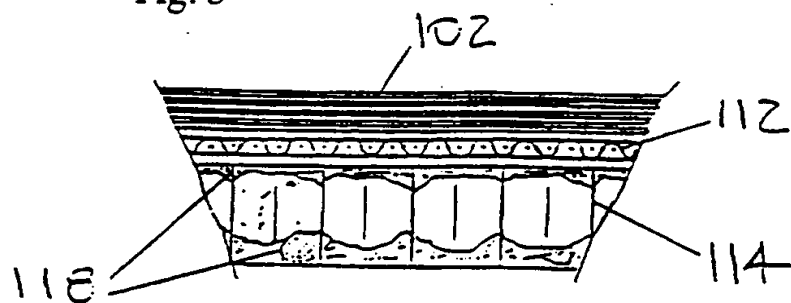


Fig. 3



PRIOR ART

Fig. 4

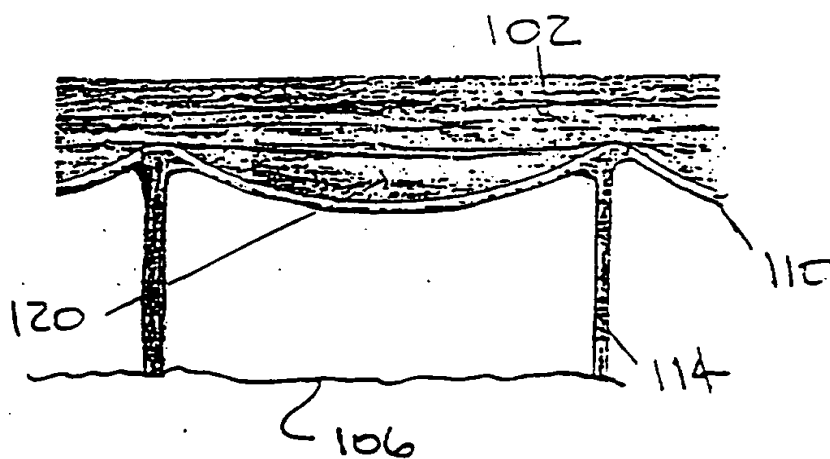


Fig. 5

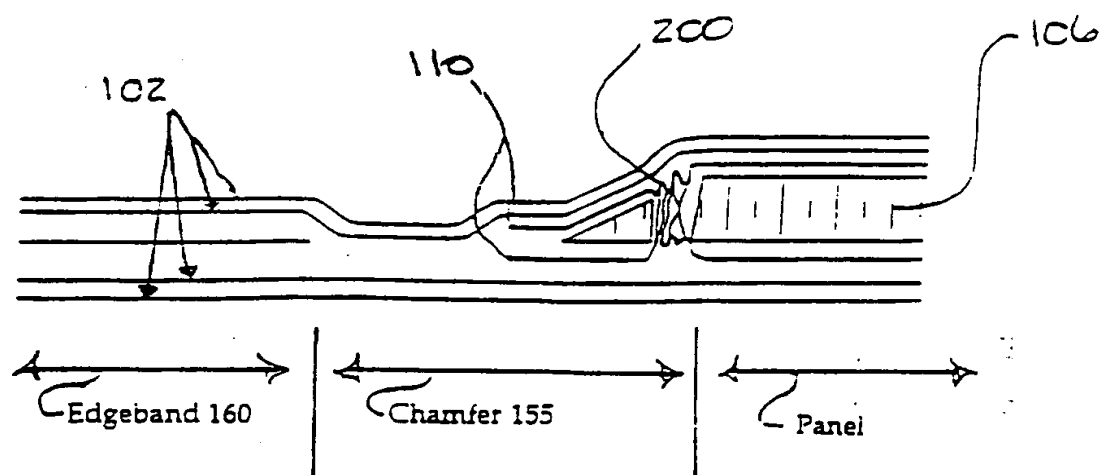
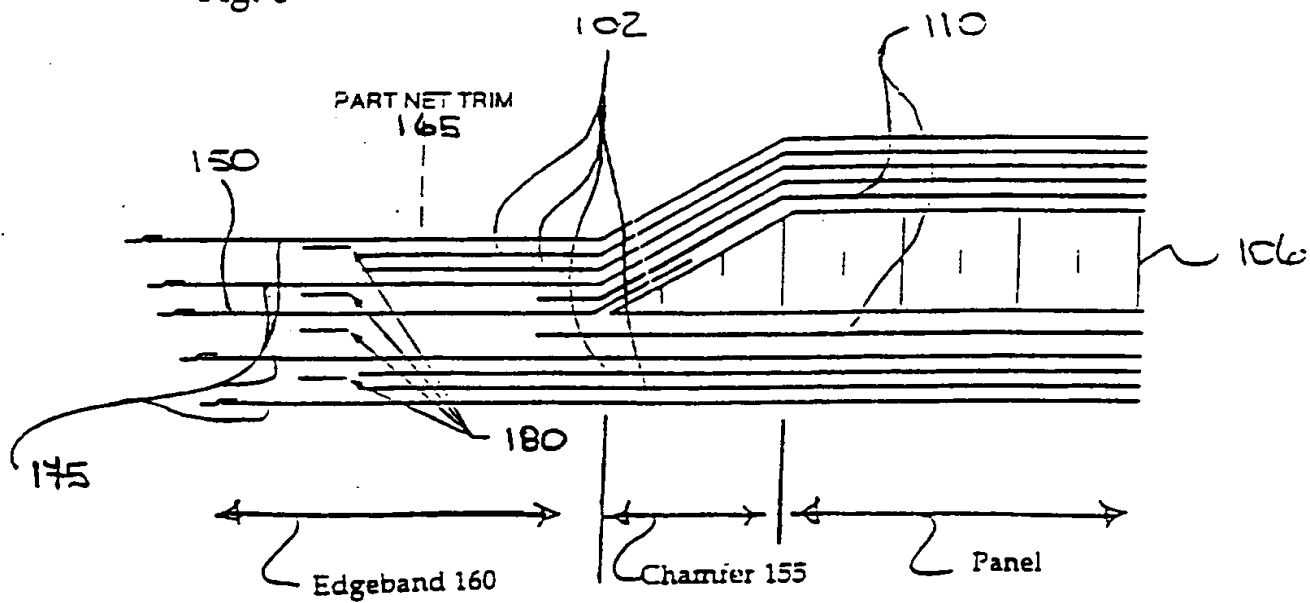


Fig. 6



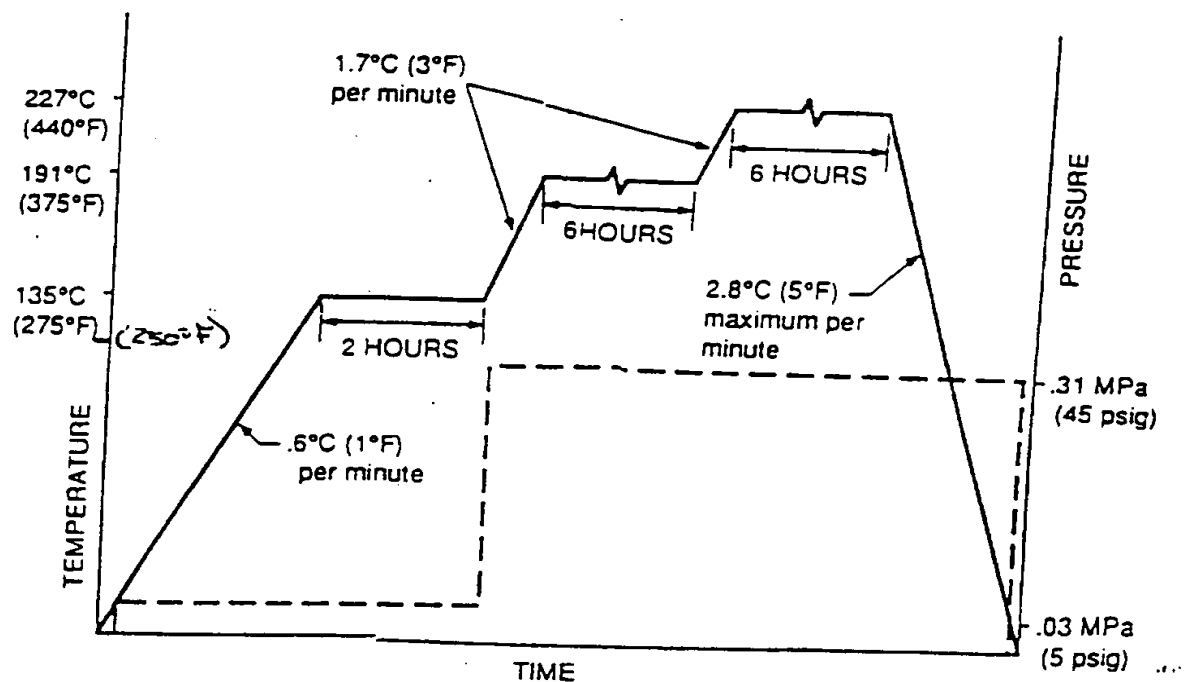


Fig. 7

INTERNATIONAL SEARCH REPORT

Internat'l Application No
PCT/US 97/00075

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 B32B3/12 B32B7/12

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 B32B B29D

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 4 954 382 A (RIEFLER R SCOTT ET AL) 4 September 1990	1,3-6
A	see column 2, line 7-47-65 - column 3, line 1-2; figure 2	2
Y	see column 4, line 25-43 - column 5, line 4-22-68; claims 1-5; example 1; table 1	7-13
Y	see column 6, line 24-26 - column 8, line 2-5	14-24
X	GB 1 391 558 A (BOEING CO) 23 April 1975	6,7, 10-12
Y	see page 2, line 38-50 - page 3, line 1-6-45; claims 13,14; figures 1-4 see page 4, line 24-32	7-13
	-/--	

☒ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

* Special categories of cited documents:

- *A* document defining the general state of the art which is not considered to be of particular relevance
- *E* earlier document but published on or after the international filing date
- *L* document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
- *O* document referring to an oral disclosure, use, exhibition or other means
- *P* document published prior to the international filing date but later than the priority date claimed

- *T* later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
- *X* document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
- *Y* document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
- *&* document member of the same patent family

Date of the actual completion of the international search

27 May 1997

Date of mailing of the international search report

20.06.97

Name and mailing address of the ISA

European Patent Office, P.B. 5818 Patentlaan 2
NL - 2280 HV Rijswijk
Tel. (+ 31-70) 340-2040, Tx. 31 651 epo nl,
Fax (+ 31-70) 340-3016

Authorized officer

Derz, T

INTERNATIONAL SEARCH REPORT

International Application No

PCT/US 97/00075

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 4 598 007 A (KOURTIDES DEMETRIUS A ET AL) 1 July 1986 see column 9, line 13 - column 10, line 21; claims 1-12,14 ---	7
A	EP 0 352 993 A (SHORT BROTHERS PLC) 31 January 1990 see column 4 - column 5; claims 1,4,13; figure 2 ---	
A	EP 0 136 096 A (FORD AEROSPACE & COMMUNICATION) 3 April 1985 see the whole document ---	
A	US 3 899 626 A (STEFFEN JOSEPH) 12 August 1975 see claims 1,4,5 ---	1,2,4
P,Y	EP 0 711 652 A (EUROCOPTER FRANCE) 15 May 1996 see the whole document -----	14-24

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No

PCT/US 97/00075

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 4954382 A	04-09-90	AT 132428 T AU 620931 B AU 4393989 A CA 2001761 A DE 68925340 D DE 68925340 T EP 0366979 A ES 2082764 T JP 2170834 A US 5141804 A	15-01-96 27-02-92 10-05-90 01-05-90 15-02-96 27-06-96 09-05-90 01-04-96 02-07-90 25-08-92
GB 1391558 A	23-04-75	CA 985151 A DE 2301180 A FR 2176678 A JP 1048307 C JP 49013926 A JP 55039461 B	09-03-76 04-10-73 02-11-73 28-05-81 06-02-74 01-10-80
US 4598007 A	01-07-86	NONE	
EP 0352993 A	31-01-90	AU 620431 B AU 3988089 A DE 68909348 D DE 68909348 T ES 2044126 T WO 9000968 A GB 2223448 A,B JP 3501591 T US 5543198 A	20-02-92 19-02-90 28-10-93 13-01-94 01-01-94 08-02-90 11-04-90 11-04-91 06-08-96
EP 0136096 A	03-04-85	CA 1239572 A JP 60092831 A	26-07-88 24-05-85
US 3899626 A	12-08-75	FR 2198835 A AU 6013473 A BE 804702 A CA 995119 A CH 577534 A DE 2345796 A GB 1423613 A	05-04-74 13-03-75 11-03-74 17-08-76 15-07-76 21-03-74 04-02-76

INTERNATIONAL SEARCH REPORT
Information on patent family members

International Application No
PCT/US 97/00075

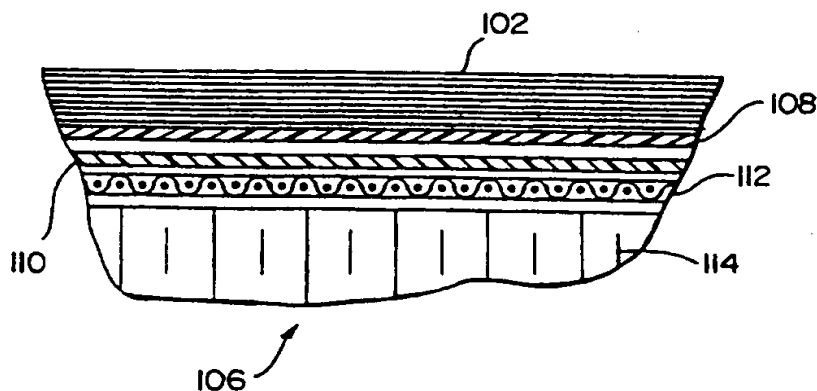
Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 3899626 A		JP 49064648 A LU 68392 A NL 7312128 A	22-06-74 14-03-74 13-03-74
EP 0711652 A	15-05-96	FR 2726500 A	10-05-96



INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification ⁶ : B32B 3/12, 7/12		A1	(11) International Publication Number: WO 97/25198
			(43) International Publication Date: 17 July 1997 (17.07.97)
(21) International Application Number: PCT/US97/00075		(81) Designated States: AL, AM, AT, AU, AZ, BB, BG, BR, BY, CA, CH, CN, CZ, DE, DK, EE, ES, FI, GB, GE, HU, IL, IS, JP, KE, KG, KP, KR, KZ, LK, LR, LS, LT, LU, LV, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, TJ, TM, TR, TT, UA, UG, UZ, VN, ARIPO patent (KE, LS, MW, SD, SZ, UG), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, ML, MR, NE, SN, TD, TG).	
(22) International Filing Date: 6 January 1997 (06.01.97)			
(30) Priority Data: 08/587,160 11 January 1996 (11.01.96) US 08/616,903 15 March 1996 (15.03.96) US 08/620,829 20 March 1996 (20.03.96) US			
(71) Applicant: THE BOEING COMPANY [US/US]; P.O. Box 3707, M.S. 13-08, Seattle, WA 98124-2207 (US).		Published <i>With international search report. Before the expiration of the time limit for amending the claims and to be republished in the event of the receipt of amendments.</i>	
(72) Inventors: HARTZ, Dale, E.; 21316 - 188th Avenue S.E., Renton, WA 98058 (US). HOPKINS, William, B.; 2740 Mountlake Boulevard E., Seattle, WA 98112 (US). PEDERSON, Christopher, L.; 4749 - 37th Avenue S.W., Seattle, WA 98126 (US). ERICKSON, Dave, G.; Apartment #168, 15031 B. Military Road South, Seatac, WA 98108 (US). CORBETT, Darrell, H.; 26025 S.E. 192nd Street, Maple Valley, WA 98038 (US). SMITH, Stuart, A.; 10923 S.E. 220th Place, Kent, WA 98031 (US).			
(74) Agent: HAMMAR, John, C.; The Boeing Company, P.O. Box 3707, M.S. 13-08, Seattle, WA 98124-2207 (US).			

(54) Title: COMPOSITE HONEYCOMB SANDWICH STRUCTURE



(57) Abstract

We eliminate resin flow into the cells of honeycomb in sandwich structure by using an unsupported film adhesive (108), a barrier layer (110), and a scrim supported adhesive layer (112) between the composite laminate (102) and the core (106). We produce superior panels with lighter weights, improved mechanical properties, and more predictable structural performance by keeping resin in the laminate rather than losing it to the core cells. We reduce core crush and ply wrinkling in composite honeycomb sandwich structure by preventing slipping of tiedown plies relative to the mandrel and to one another during autoclave curing. We produce superior panels with lighter weights, improved mechanical properties, and more predictable structural performance. The method involves applying a film adhesive to the tiedown plies in the margin of the part outside the net trim line. During heating of the autoclave and prior to the application of high pressure to the composite structure, the film adhesive cures to form a strong bond between the plies and to the mandrel. When pressure is applied, the tiedown plies are locked together and to the mandrel to prevent slippage between any layers in the panel.

FOR THE PURPOSES OF INFORMATION ONLY

Codes used to identify States party to the PCT on the front pages of pamphlets publishing international applications under the PCT.

AM	Armenia	GB	United Kingdom	MW	Malawi
AT	Austria	GE	Georgia	MX	Mexico
AU	Australia	GN	Guinea	NE	Niger
BB	Barbados	GR	Greece	NL	Netherlands
BE	Belgium	HU	Hungary	NO	Norway
BF	Burkina Faso	IE	Ireland	NZ	New Zealand
BG	Bulgaria	IT	Italy	PL	Poland
BJ	Benin	JP	Japan	PT	Portugal
BR	Brazil	KE	Kenya	RO	Romania
BY	Belarus	KG	Kyrgyzstan	RU	Russian Federation
CA	Canada	KP	Democratic People's Republic of Korea	SD	Sudan
CF	Central African Republic	KR	Republic of Korea	SE	Sweden
CG	Congo	KZ	Kazakhstan	SG	Singapore
CH	Switzerland	LI	Liechtenstein	SI	Slovenia
CI	Côte d'Ivoire	LK	Sri Lanka	SK	Slovakia
CM	Cameroon	LR	Liberia	SN	Senegal
CN	China	LT	Lithuania	SZ	Swaziland
CS	Czechoslovakia	LU	Luxembourg	TD	Chad
CZ	Czech Republic	LV	Latvia	TG	Togo
DE	Germany	MC	Monaco	TJ	Tajikistan
DK	Denmark	MD	Republic of Moldova	TT	Trinidad and Tobago
EE	Estonia	MG	Madagascar	UA	Ukraine
ES	Spain	ML	Mali	UG	Uganda
FI	Finland	MN	Mongolia	US	United States of America
FR	France	MR	Mauritania	UZ	Uzbekistan
GA	Gabon			VN	Viet Nam

COMPOSITE HONEYCOMB SANDWICH STRUCTURE

Technical Field

The present invention relates to composite honeycomb sandwich structure, and particularly to resin impregnated fabric sheets forming outer skins adhered on opposed surfaces of a honeycomb core with an intermediate barrier to eliminate resin flow from the skins to the core.

Background Art

Aerospace honeycomb core sandwich panels (having composite laminate skins cocured with adhesives to the core through autoclave processing) find widespread use today because of the high stiffness-to-weight (*i.e.*, "specific stiffness") and strength-to-weight (*i.e.*, specific strength) ratios the panels afford. Typical honeycomb core sandwich panels are described in U.S. Patents 5,284,702; 4,622,091; and 4,353,947. *Alteneder et al.*, *Processing and Characterization Studies of Honeycomb Composite Structures*, 38th Int'l SAMPE Symposium, May 10-13, 1993 (PCL Internal No. 200-01/93-AWA) discusses common problems with these panels, including core collapse (*i.e.*, core crush), skin laminate porosity, and poor tool surface finish.

U.S. Patent 5,445,861 describes composite sandwich structure for sound absorption (acoustic insulation) and other applications. The sandwich structures have seven layers as follows:

- (1) an outer skin;
- (2) a small celled honeycomb or foam core;
- (3) a frontside inner septum;
- (4) a large celled middle honeycomb core;
- (5) a backside, inner septum;
- (6) a backside, small celled honeycomb or foam core; and

(7) an inner skin.

Tuned cavity absorbers in the middle honeycomb core absorb sound. Performance of this structure suffers from resin flow to the cells of the honeycomb cores during fabrication for the reasons already discussed and because such flow alters the resonance of the structure.

Summary of the Invention

With a high flow resin system, large amounts of resin can flow into the core during the autoclave processing cycle. Such flow robs resin from the laminate, introduces a weight penalty in the panel to achieve the desired performance, and forces over design of the laminate plies to account for the flow losses. The resin loss from the laminate plies also reduces the thickness of the cured plies which compromises the mechanical performance. To achieve the desired performance and the corresponding laminate thickness, additional plies are necessary with resulting cost and weight penalties. Because the weight penalty is severe in terms of the impact on vehicle performance and cost in modern aircraft and because the flow is a relatively unpredictable and uncontrolled process, aerospace design and manufacture dictates that flow into the core be eliminated or significantly reduced. In addition to the weight penalty from resin flow to the core, we discovered that microcracking that originated in the migrated resin could propagate to the bond line and degrade mechanical performance. Such microcracking potential poses a catastrophic threat to the integrity of the panel and dictates that flow be eliminated or, at least, controlled.

Flow from the laminates to the core occurs because of viscosity reduction of the resin (*i.e.*, thinning) at the elevated processing temperatures. Therefore, prior art attempts to solve the flow problem have generally focused on retaining the ambient temperature viscosity of the resin at the curing temperatures. For example, one might alter the processing cycle to initiate

curing of the resin during a slow heat-up, low pressure step to induce resin chain growth before high temperature, high pressure completion. In this staged cure cycle, one would try to retain the resin's viscosity by building molecular weight at low temperatures. Higher molecular weight resins have inherently higher viscosity so they remain thicker and are resistant to damaging flow to the core. Unfortunately, with a staged cure cycle, too much flow still occurs, and the potential problems of microcracking still abound. Also, facesheet porosity might increase beyond acceptable limits. Furthermore, a modified cure cycle increases autoclave processing time. Increased processing time translates to a significant fabrication cost increase with risk of rejection of high value parts at the mercy of uncontrolled and inadequately understood factors.

We eliminate resin (matrix) flow into the honeycomb core for sandwich structure using high flow resin systems and results in reproducibility and predictability in sandwich panel fabrication and confidence in the structural performance of the resulting panel. We use a scrim-supported barrier film between the fiber-reinforced resin composite laminates and the honeycomb core. This sandwich structure is lighter for the same performance characteristics than prior art panels because the resin remains in the laminate (skin) where it provides structural strength rather than flowing to the core where it is worthless, introducing excess weight and potential panel failure. We also generally use an unsupported film adhesive between the barrier film and the laminates to bond the laminates to the barrier film. With these layers (which might be combined into one product), they achieved improved performance, retained the resin in the laminates and thereby reduced excess resin that designers otherwise needed to design into the panels to account for resin flow into the core, and reliably fabricated panels in which they had structural confidence.

Core crush frequently occurred in the chamfer region of honeycomb core when we cured a panel having a scrim-supported barrier film, particularly

when they tried to use lighter weight core materials. We can reduce core crush in these panels by including a tiedown ply in contact with the core beneath the barrier film (and adhesive) because the tiedown ply reduced slippage of the barrier film relative to the core during curing.

Controlling core slippage in the present invention allows us to use lighter density honeycomb core to produce structures without costly scrap due to core crush. We reduce manufacturing costs both by saving time, materials, and rework/scrap and by improving the reliability of the manufacturing process to produce aerospace-quality panels having the highest specific strength and specific stiffness.

The added tiedown ply means that three or more tiedown plies will be included in the final preform of the panel. In conventional practice, there will also be tiedown plies on the outer surfaces of the panel and possibly between the laminate and the adhesive barrier film. Each tiedown ply extends outwardly from the part beyond the net trim line of the finished product. Conventionally, the tiedown plies are secured individually and sequentially to the layup mandrel with tape. Especially when using low density core it is important to fix the relation of the plies to one another and to the mandrel. Failure of the tape results in facesheet ply wrinkles or core crush. Core crush could still occasionally occur when the tiedown ply in contact with the core pulled away from the tape securing it to the mandrel, slipping relative to the other tiedown plies. The adhering strength of the tape alone was insufficient to overcome the forces acting on the core in a panel when we applied autoclave pressure. We discovered how to adhere the tiedown plies to each other reliably, easily, and inexpensively. Adhering the plies to each other distributes the forces acting on any individual ply among all the tiedown plies, reducing the maximum force seen by the tape adhering the tiedown plies to the mandrel. While described with respect to a composite honeycomb sandwich structure,

the adhering method is generally applicable to all applications involving tiedown plies in composite construction.

Thus, in one aspect, the present invention relates to an improvement in the manufacture of composite structure, especially composite honeycomb sandwich structure, where tiedown plies are used to secure the part during autoclave curing at elevated temperature and pressure. To lock the tiedown plies together so that there is no movement of one ply relative to another, we use a lower temperature curing adhesive to cure and to connect the several plies together during the early stages of autoclave curing prior to applying pressure. We apply the adhesive outside the net trim line for the part, so that it is removed during finishing of the part.

In another aspect, the present invention relates to adhering tiedown plies to one another during the construction of composite structure, especially during the autoclave processing at elevated temperature and pressure of composite honeycomb sandwich structure. The conventional practice of taping the tiedown plies to the mandrel alone is unsatisfactory, because the taping must be sufficient to prevent slippage of any ply or of one ply relative to another. We discovered that we could adhere the plies effectively to one another to reduce maximum forces on the tape by applying a low temperature curing film adhesive between the tiedown plies just outside the net trim line for the part. In the autoclave, this film adhesive melts and cures at a lower temperature than the resin in the laminates so that it bonds the tiedown plies together prior to increasing the autoclave pressure at the higher temperature where the laminate resin flows and cures. The film adhesive eliminates movement of the tiedown plies relative to one another. In our preferred embodiment for a bismaleimide (BMI) sandwich panel, we prefer to use an adhesive that cures at about 250°F (121°C) for a BMI that cures around 375°F (191°C), and post-cures around 440°F.

Brief Description of the Drawings.

Fig. 1 illustrates a typical composite honeycomb sandwich structure.

Fig. 2 is a schematic, partial sectional view of the skin-core interface in sandwich structure having a scrim-supported barrier film to prevent resin flow from the skin to the core.

Fig. 3 is a schematic, partial sectional view of prior art honeycomb sandwich structure, suffering resin flow to the core, using a supported film adhesive without a barrier film.

Fig. 4 is another schematic, partial sectional view showing sandwich structure with resin depletion in the skin, but where the resin is prevented from reaching the core with a bulging, unsupported barrier film.

Fig. 5 is a schematic, sectional elevation showing core crush of a honeycomb sandwich panel caused by core and barrier film slippage.

Fig. 6 is another schematic, sectional elevation showing the use of a tiedown ply to reduce core crush.

Fig. 7 is a graph of a typical autoclave curing cycle for making composite honeycomb sandwich panels, showing that our tiedown adhesive cures prior to the application of high pressure in the cycle.

Detailed Description of a Preferred Embodiment

As a frame of reference for this description, we will initially describe typical composite honeycomb sandwich structure. Then, we will turn to our invention of a method of reliably adhering the tiedown plies together.

A composite honeycomb sandwich panel minimizes, eliminates, or significantly reduces resin flow from the laminates to the core, thereby permitting a simpler processing cycle that is more robust for the manufacture of aerospace structure. Such a sandwich panel 100 (Fig. 1) generally has outer facesheets or skins 102 adhered to a central honeycomb core 106. The finished skins 102 comprise laminates of layers of fiber-reinforced organic matrix resin

in a cured and consolidated composite form. The core 106 can be paper, synthetic paper, metal, composite, or the like, as appropriate for the application. In panels of the present invention, we obtain higher specific strengths and higher specific stiffnesses because we reduce core crush during autoclave curing by incorporating at least one tiedown ply between the core 106 and skin 102 to reduce damaging slippage between the core and skin that otherwise often occurs.

To prevent flow of resin from the composite laminate skin to the core, we use an unsupported film adhesive 108 (Fig. 2), a barrier film 110, and a scrim-supported film adhesive 112 between the skin 102 and the core 106 to keep resin out of the cells 114 of the core 106.

Fig. 3 illustrates the core-filling problems that can result when a film adhesive 112 is used alone without the barrier film 110 and film adhesive 108. Cells 114 of the honeycomb fill with resin 118 which migrates from the laminates and which thereby depletes the resin in the skin 102. Resin depletion impacts structural performance because it reduces ply thickness. Resin depletion increases total weight since the cell resin 118 is simply waste. In all cases, uncontrolled resin flow and depletion makes the panel suspect, especially to microcracking that can begin in the cell resin 118 during thermal cycling and migrate to the fiber-reinforced skin 102, especially at the bond line between the skin 102 and core 106.

Fig. 4 illustrates undesirable bulging that can occur if a barrier film 110 is used without a scrim-supported film adhesive 112 to try to eliminate cell resin 118. Here, a waste resin bulge 120 protrudes downwardly into the cells 114 of the honeycomb core 106. While the resin is contained in the bulge 120, the skin 102 is still depleted in resin. The flow of resin to bulge 120 imposes structural performance and weight penalties comparable to the uncontrolled condition illustrated in Fig. 3.

As shown in Fig. 2 with the film adhesive 108, barrier film 110, and scrim-supported film adhesive 12, resin flow is checked without cell resin 118 or resin bulges 120. We discovered, however, that the barrier film produced a slip plane between the laminate skins and the core which often resulted in core crush during the autoclave processing cycle. In 22 of 31 test panels, in fact, we experienced core crush in our initial trials. This rate of failure was unacceptable from a cost and schedule perspective. Our tiedown plys in the chamfer region reduce the frequency of or eliminate damaging core slippage and the core crush attributable to such slippage.

For bismaleimide laminated skins made with RIGIDITE® 5250-4-W-IM7-GP-CSW, RIGIDITE® 5250-4-W-IM7-GP-CSX, and RIGIDITE® 5250-4-W-IM7-GP-PW prepreg from Cytec Engineered Materials, Inc. (Cytec), the film adhesive 108 preferably is 0.015 psf METLBOND® 2550U adhesive, also available from Cytec. The film adhesive provides additional resin to promote a quality bond between the laminate and barrier film 110. The barrier film 110 preferably is a 0.001 inch thick, bondable grade, surface treated KAPTON® polyimide barrier film capable of withstanding the cure cycle to provide a resin impermeable membrane between the skin 102 and core 106. The scrim preferably is fiberglass, "Style 104" fiber cloth and the film adhesive 112 is 0.06 psf METLBOND® 2550G adhesive, available from Cytec. The scrim-supported film adhesive prevents the barrier film from bulging into the core cells, thereby retaining the resin in the laminate (i.e., skin layers) so that the cured ply thickness is maximized and thereby, we achieve maximum performance at minimum weight for the panels.

The film adhesive 108, barrier film 110, and film adhesive 112 can be purchased as a single item from Cytec as METLBOND® 2550B-.082 36".

The plys of the skin 102 typically are prepregs of carbon fiber impregnated with bismaleimide thermoset resin, although the present invention applies to other resin systems. Tows might be used in place of the prepreg.

The film adhesive 108 should be tailored to achieve an adequate bond between the skin 102 and barrier film 110. The honeycomb core generally is HRP Fiberglass Reinforced Phenolic honeycomb available from Hexcel.

The supported film adhesive and barrier film layers in the sandwich structure also function as corrosion barriers between the skin 102 and core 106 in the case where the core is metal, such as aluminum, and the skin includes a galvanically dissimilar material, such as carbon fiber.

Additional information concerning preferred panels is presented in the technical paper: *Hartz et al.*, "Development of a Bismaleimide/Carbon Honeycomb Sandwich Structure," SAMPE, March, 1996, which we incorporate by reference. This paper describes both the *Hartz et al.* barrier film improvement, the tiedown ply method, and the adhering method of the present invention.

The *Hartz*-type panels provide mechanical and physical edgeband properties equivalent to solid BMI/carbon laminate (cured at 0.59 MPa (85 psig)). Our tests confirm that in our panels the edgeband cured-ply-thickness is equivalent to a solid laminate and that the edgeband 160 (Figs. 5 & 6) met the requirements of the solid laminate nondestructive inspection specification. The edgeband and facesheet mechanical performance improved over results we achieved with sandwich structure lacking the scrim-supported adhesive, barrier film, adhesive combination. The flatwise tensile mechanical performance also met design requirements.

Preconditioning the core to eliminate volatile evolution during curing by heating the core to about 235° C (455° F), prior to laying up the sandwich panel, especially for phenolic core, eliminates core-laminate disbonding otherwise caused by outgassing from the core.

Core crush 200 (Fig. 5) occurs in the chamfer region 155 when the barrier film 110 and core 106 slip relative to the facesheets 102 when autoclave pressure is applied and when the resin is melted. As shown in Fig. 5, the

barrier films 100 and core 106 have moved toward the right to compress the core in the chamfer region 155 to produce the core crush 200. The skin 102 has sagged in the edgeband region 160 where the core moved away.

Referring now to Fig. 6, the improved honeycomb sandwich panel includes at least one tiedown ply 150 in contact with the core 106 along a chamfer 155. Such a chamfer (*i.e.* an angled transition in the core, often at the edgeband 160) typically occurs around the periphery of the panel, but it might also occur intermediate of the panel at join lines or hard points where fasteners or pass-throughs might be necessary in the assembled structure.

Typically we use a single ply 150 of carbon fiber or fiberglass fabric with a conventional 0/90 fiber orientation in the fabrication of bismaleimide panels having 5 or 8 lb/ft³ HRP core, like *Hartz et al.* describe. The tiedown ply 150 functions to prohibit or to limit slippage of the skin relative to the core so as to reduce core crush otherwise attributable to the slippage. The tiedown ply 150 anchors the core with the inherent roughness of the fabric when the preform is heated during the autoclave processing cycle and the matrix resin softens, melts, and, for high flow resins, essentially liquefies. With these panels, we can save between 2.5-4 lb/ft³ of core because we can use lighter density honeycomb core without suffering core crush. For a fighter, this change can save as much as 25 lbs per vehicle.

As shown in Fig. 6, the tiedown ply 150 is a narrow, peripheral strip that contacts the core 106 along at least a portion of the chamfer 155 for about 1 inch overlap with the core 106 and extends outward into the edgeband 160 beyond the trimline 165 of the part. The tiedown ply 150 might be on either the flat side of the chamfer or the angled surface (which is how we show it in Fig. 6). The key factor is that the tiedown ply 150 contact the core beneath the adhesive and barrier film 110 which is used to bond the laminate skin to the core. The tiedown ply 150 is cutaway everywhere in the body of the part other than a narrow peripheral area in the chamfer region, and forms a peripheral

frame around the edge of the panel. In this way, the tiedown ply 150 allows an adhesive interface between the core 106 and the skins 102 in the panel region.

Traditionally, in making a *Hartz*-type panel, we use four complete cover sheet tiedown plies 175 in an effort to anchor the layers and the core, and we show all these plies in Fig. 6. These traditional plies 175 were commonly used in sandwich panel fabrication prior to introducing the *Hartz*-type barrier film, and we commonly use them all, although we believe we can now eliminate all but the outer plies and the peripheral, core contacting tiedown ply 150. That is, we would use three total plies rather than five, as Fig. 6 shows.

The tiedown plies 150 and 175 extend through the edgeband 160 beyond the net trim line 165 to anchoring points that we tape to the layup mandrel. To further prevent slippage of the tiedown plies, we have incorporated a low curing (*i.e.* 121°C for BMI panels) film adhesive 180 between the tiedown plies just outside the net trim line of the part. The film adhesive 180 eliminates movement of one ply relative to the others when we apply pressure during the autoclave curing cycle. Curing at a temperature of about 100 - 150°F below the curing temperature of the laminate resin, the tiedown adhesive cures before we need to increase the autoclave pressure and the cured adhesive bonds the tiedown plies to one another. Using the adhering method eliminates relative movement of the plies and eliminates facesheet wrinkles and core crush that otherwise can occur.

The tiedown method saves material, reduces cost, and saves weight, because it uses the "picture frame" peripheral tiedown ply 150 (with the traditional, internal sheets omitted). The normal tiedown procedure entails plies on the outer surfaces of the skins and internally between the skin and underlying adhesive (Fig. 5). A traditional tiedown system will fail without the "picture frame" ply because the barrier film 110 permits the core to slip. The Corbett and Smith method will fail occasionally without the adhering method of the present invention.

For lightweight core (*i.e.* 5-8 lb/ft³) with the bismaleimide prepreg and adhesive system previously described, we hold the chamfer angle to $20^{\circ} \pm 2^{\circ}$.

By "chamfer" we mean an angled, cut region (a ramp) of the honeycomb core tapering from full thickness to no thickness with a steady slope. A chamfer is used at the edge band of a composite honeycomb sandwich panel to provide a smooth transition between the structural body of the panel that has the embedded honeycomb and a connecting edge band lacking any honeycomb core. The method of the present invention allows us to use much steeper chamfer angles than traditional practices often require if one is to avoid core crush without one tiedown ply. While we prefer a 20° chamfer, we believe that we could increase the angle to whatever angle suited the panel design requirements.

By "autoclave processing" we mean the cycle of elevated temperature and pressure applied to the panel to consolidate and cure resin in the laminate while bonding or otherwise adhering the cured laminate to the honeycomb core. Our preferred cycle is illustrated in Fig. 7. Our adhesive for the tiedown plies cures at about 250°F (121°C) so it cures prior to the increase in autoclave pressure that can introduce relative motion between layers in the panel.

If core crush occurs, the damage to the panel is generally so extensive that repair is impossible so the part is scrapped. The cost of today's advanced composite resins and reinforcing fibers requires a process that virtually eliminates core crush. Otherwise, the processing costs are prohibitive. With panels being designed as close to the design edge as possible, core crush is a significant issue. The method of the present invention reduces cores crush and ply movement or wrinkling.

While we have described preferred embodiments, those skilled in the art will readily recognize alterations, variations, and modifications, which might be made without departing from the inventive concept. Therefore, interpret the claims liberally with the support of the full range of equivalents known to those

of ordinary skill based upon this description. The examples are given to illustrate the invention and are not intended to limit it. Accordingly, define the invention by the claims and limit the claims only as necessary in view of the pertinent prior art.

We claim:

1. Composite honeycomb sandwich structure, comprising:
 - (a) a honeycomb core, having core cells;
 - (b) at least one composite laminate having plies of fiber-reinforced matrix resin adhered to the core;
 - (c) a film barrier layer between the laminate and the core to bond the laminate and core and to eliminate resin flow from the laminate into the core cell; and
 - (d) a film adhesive with supporting scrim between the barrier layer and the core to eliminate resin flow to or sagging of the barrier film into the core cells.
2. The structure of claim 1 wherein the laminate includes bismaleimide matrix resin.
3. The structure of claim 1 wherein the barrier layer is a bondable grade, polyimide.
4. The structure of claim 2 wherein the film adhesive includes bismaleimide.
5. The structure of claim 4 further comprising an unsupported film adhesive layer between the barrier layer and the laminate.
6. A method for eliminating the flow of resin from laminate skins of a composite honeycomb sandwich panel to cells of the honeycomb comprising the step of:

containing the resin in the skin with a scrim supported barrier film that is impermeable to the resin and that is adhered between the skin and honeycomb.

7. A method for adhering tiedown plies together in the manufacture of composite structure, comprising the steps of:

- (a) assembling on the layup mandrel a composite preform in the shape of the composite structure, the preform having at least one resin-impregnated laminate and at least two tiedown plies; and
- (b) adhering the tiedown plies to one another with a film adhesive applied to the plies outside a net trim line of the composite structure.

wherein the film adhesive cures at a temperature lower than the resin in the laminate.

8. The method of claim 7 wherein the laminate includes bismaleimide matrix resin.

9. The method of claim 7 wherein the preform includes a barrier film made from a bondable grade, polyimide adjacent the laminate.

10. The method of claim 8 wherein the preform includes a honeycomb core and an adhesive between the barrier film and core.

11. The method of claim 10 wherein the preform includes a film adhesive layer between the barrier film and the laminate.

12. The method of claim 10 wherein the preform includes a supporting scrim between the barrier film adhesive and the core to prevent sagging of the barrier film into the core cells.

13. The method of claim 12 wherein the preform includes a tiedown ply in contact with the core between the adhesive and core.

14. A method for reducing core crush in a chamfered composite honeycomb sandwich panel having a resin-impregnated laminate adhered to a honeycomb core, the core having a chamfer, comprising the steps of:

- (a) contacting a tiedown ply with the honeycomb core of the panel in the region of the chamfer to prevent slippage between the core and the laminate; and
- (b) assembling tiedown plies over outer surfaces of the laminate;
- (c) adhering the tiedown plies together and to the layup mandrel with a lower temperature curing adhesive applied to the tiedown plies outside a net trim line of the panel,

wherein the adhesive melts and cures prior to the application of autoclave pressure and prior to the melt and flow of the resin in the laminate.

15. The method of claim 14 wherein the laminate includes a barrier film to prevent resin flow from facesheets of the laminate to the core cells, and wherein one tiedown ply is between the barrier film and core.

16. Composite honeycomb sandwich structure having improved resistance to core crush, comprising:
- (a) a honeycomb core, having core cells and a peripheral chamfer;
 - (b) at least one composite laminate having plies of fiber-reinforced matrix resin adhered to the core;
 - (c) a barrier film adhesive between the laminate and the core to bond the laminate and core and to eliminate resin flow from the laminate into the core cells; and
 - (d) a peripheral tiedown ply in contact with the chamfer of the core beneath the adhesive to eliminate slippage of the barrier film relative to the core and, in so doing, to reduce core crush.
17. The structure of claim 16 wherein the laminate includes bismaleimide matrix resin.
18. The structure of claim 16 wherein the barrier film is a bondable grade, polyimide.
19. The structure of claim 17 wherein the adhesive includes bismaleimide.
20. The structure of claim 19 further comprising a film adhesive layer between the barrier film and the laminate.
21. The structure of claim 16 further comprising a supporting scrim between the barrier film adhesive and the core to prevent sagging of the barrier film into the core cells.

22. Composite honeycomb sandwich structure resistant to core crush caused by slippage of a composite laminate along a chamfer of a honeycomb core, comprising:

- (a) a honeycomb core having a chamfer;
- (b) a tiedown ply contacting the chamfer; and
- (c) at least one laminate adhered to the core through the tiedown ply at the chamfer

wherein the tiedown ply prevents damaging slippage of the laminate relative to the core that would produce core crush during autoclave curing of the structure to adhere the core to the laminate.

23. A method for reducing core crush in a chamfered composite honeycomb sandwich panel having a laminate adhered to a honeycomb core, the core having a chamfer, comprising the step of:

contacting a tiedown ply with the honeycomb core of the panel in the region of the chamfer to prevent slippage between the core and the laminate.

24. The method of claim 23 wherein the laminate includes a barrier film to prevent resin flow from the laminate to the core cells.

-1/3-

FIG. 1

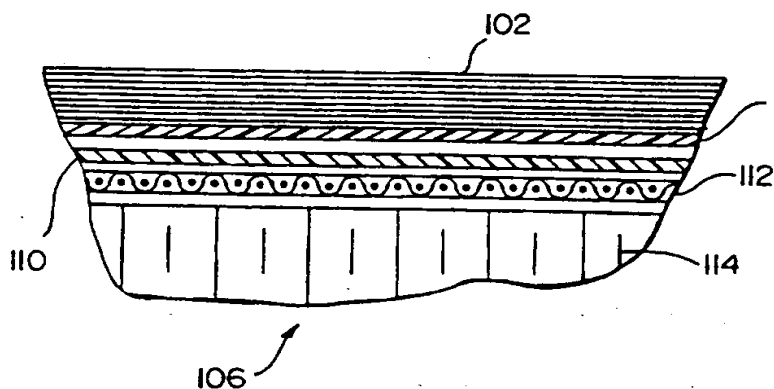
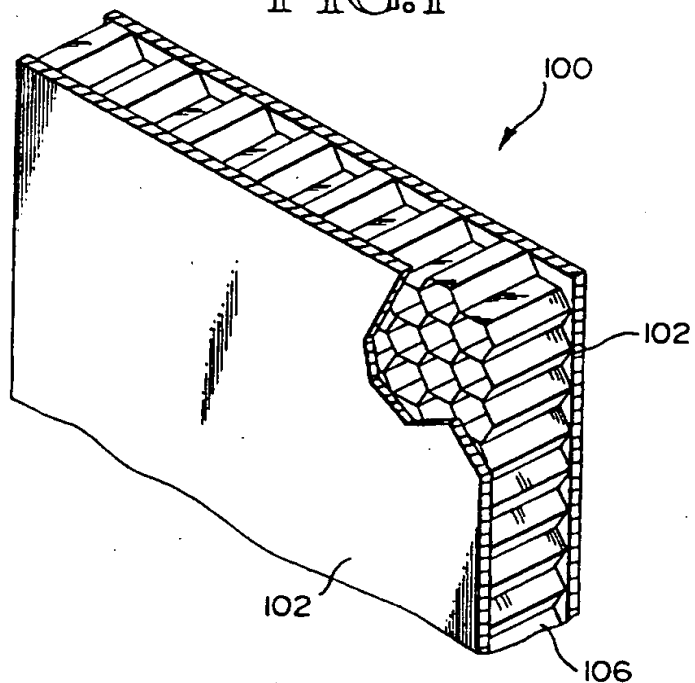


FIG. 2

FIG. 3
PRIOR ART

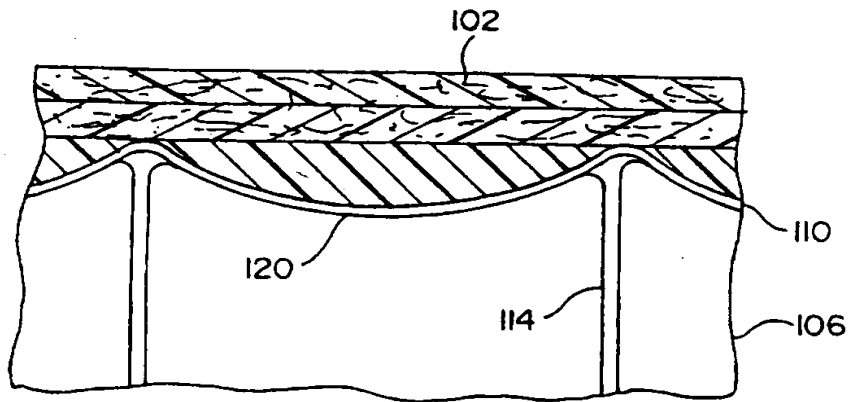
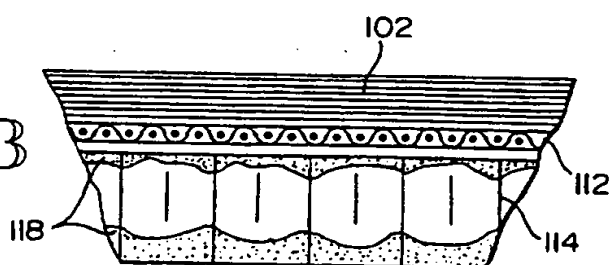


FIG. 4
PRIOR ART

- 2/3 -

FIG. 5

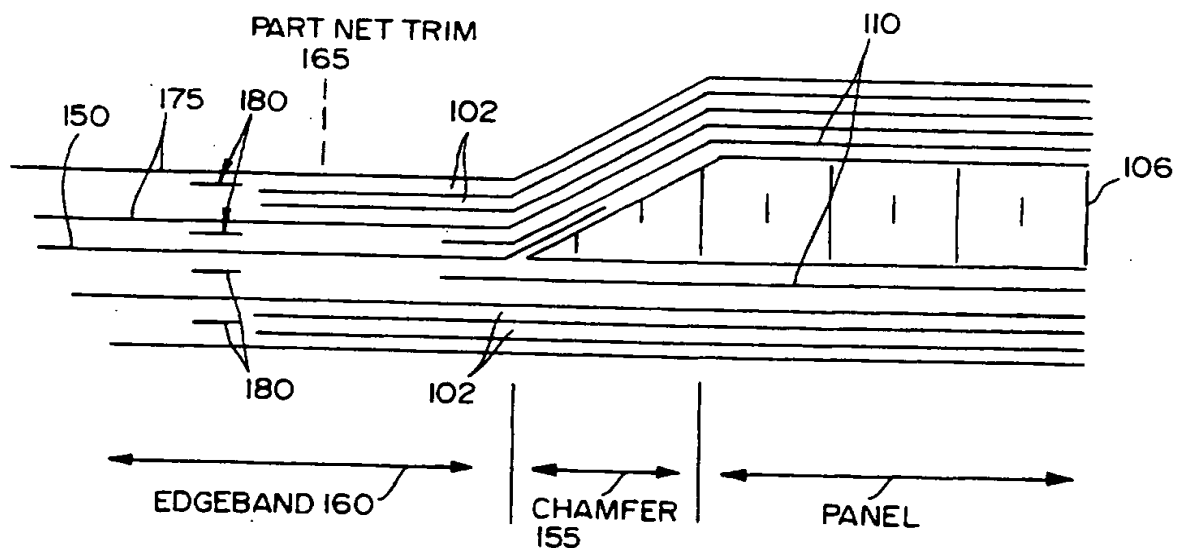
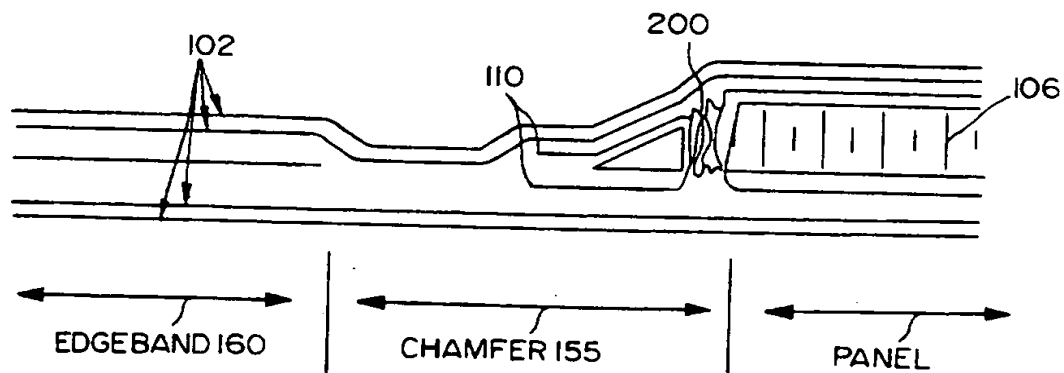


FIG. 6

SUBSTITUTE SHEET (RULE 26)

- 3/3 -

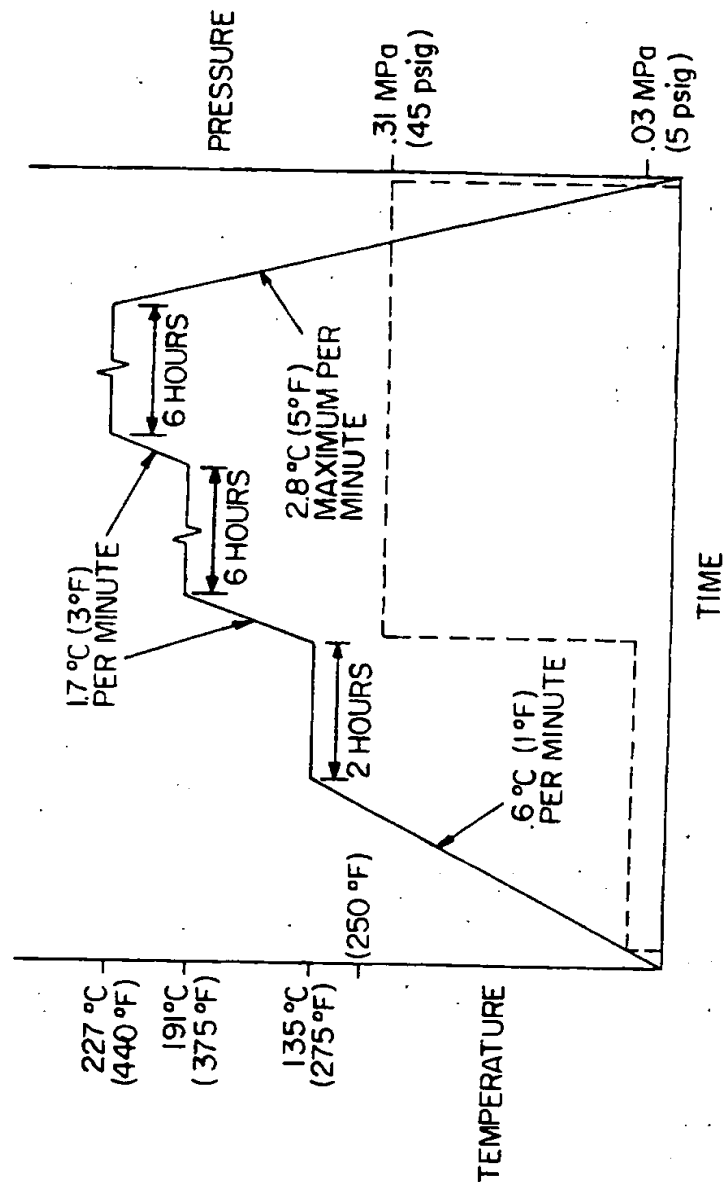


FIG. 7

SUBSTITUTE SHEET (RULE 26)

INTERNATIONAL SEARCH REPORT

Internat'l Application No

PCT/US 97/00075

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 B32B3/12 B32B7/12

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 6 B32B B29D

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 4 954 382 A (RIEFLER, R SCOTT ET AL) 4 September 1990	1,3-6
A	see column 2, line 7-47-65 - column 3, line 1-2; figure 2	2
Y	see column 4, line 25-43 - column 5, line 4-22-68; claims 1-5; example 1; table 1	7-13
Y	see column 6, line 24-26 - column 8, line 2-5	14-24
X	GB 1 391 558 A (BOEING CO) 23 April 1975	6,7, 10-12
Y	see page 2, line 38-50 - page 3, line 1-6-45; claims 13,14; figures 1-4 see page 4, line 24-32	7-13
	--- -/--	

☒ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

* Special categories of cited documents:

- *A* document defining the general state of the art which is not considered to be of particular relevance
- *E* earlier document but published on or after the international filing date
- *L* document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
- *O* document referring to an oral disclosure, use, exhibition or other means
- *P* document published prior to the international filing date but later than the priority date claimed

- *T* later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
- *X* document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
- *Y* document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.
- *A* document member of the same patent family

Date of the actual completion of the international search

27 May 1997

Date of mailing of the international search report

20.06.97

Name and mailing address of the ISA

European Patent Office, P.B. 5818 Patentlaan 2
NL - 2280 HV Rijswijk
Tel. (+ 31-70) 340-2040, Tx. 31 651 epo nl,
Fax (+ 31-70) 340-3016

Authorized officer

Derz, T

INTERNATIONAL SEARCH REPORT

Intern nal Application No
PCT/US 97/00075

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT		
Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 4 598 007 A (KOURTIDES DEMETRIUS A ET AL) 1 July 1986 see column 9, line 13 - column 10, line 21; claims 1-12,14 ---	7
A	EP 0 352 993 A (SHORT BROTHERS PLC) 31 January 1990 see column 4 - column 5; claims 1,4,13; figure 2 ---	
A	EP 0 136 096 A (FORD AEROSPACE & COMMUNICATION) 3 April 1985 see the whole document ---	
A	US 3 899 626 A (STEFFEN JOSEPH) 12 August 1975 see claims 1,4,5 ---	1,2,4
P,Y	EP 0 711 652 A (EUROCOPTER FRANCE) 15 May 1996 see the whole document -----	14-24

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No

PCT/US 97/00075

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 4954382 A	04-09-90	AT 132428 T AU 620931 B AU 4393989 A CA 2001761 A DE 68925340 D DE 68925340 T EP 0366979 A ES 2082764 T JP 2170834 A US 5141804 A	15-01-96 27-02-92 10-05-90 01-05-90 15-02-96 27-06-96 09-05-90 01-04-96 02-07-90 25-08-92
GB 1391558 A	23-04-75	CA 985151 A DE 2301180 A FR 2176678 A JP 1048307 C JP 49013926 A JP 55039461 B	09-03-76 04-10-73 02-11-73 28-05-81 06-02-74 01-10-80
US 4598007 A	01-07-86	NONE	
EP 0352993 A	31-01-90	AU 620431 B AU 3988089 A DE 68909348 D DE 68909348 T ES 2044126 T WO 9000968 A GB 2223448 A,B JP 3501591 T US 5543198 A	20-02-92 19-02-90 28-10-93 13-01-94 01-01-94 08-02-90 11-04-90 11-04-91 06-08-96
EP 0136096 A	03-04-85	CA 1239572 A JP 60092831 A	26-07-88 24-05-85
US 3899626 A	12-08-75	FR 2198835 A AU 6013473 A BE 804702 A CA 995119 A CH 577534 A DE 2345796 A GB 1423613 A	05-04-74 13-03-75 11-03-74 17-08-76 15-07-76 21-03-74 04-02-76

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No

PCT/US 97/00075

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 3899626 A		JP 49064648 A	22-06-74
		LU 68392 A	14-03-74
		NL 7312128 A	13-03-74
<hr/>			
EP 0711652 A	15-05-96	FR 2726500 A	10-05-96
<hr/>			

THIS PAGE BLANK (USPTO)